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Life-cycle assessment of soybean-based biodiesel in Europe: comparing grain, oil and biodiesel import from Brazil

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ABSTRACT

The purpose of this article is to present a life-cycle assessment of soybean methyl ester addressing three alternative pathways: biodiesel totally produced in Brazil and exported to Portugal; biodiesel produced in Portugal using soybean oil and soybean imported from Brazil. Soybean cultivation was assessed for four states in Brazil: Mato Grosso; Goiás; Paraná and Rio Grande do Sul. A life-cycle inventory and model of biodiesel was implemented, including land-use change, soybean cultivation, oil extraction and refining, transesterification and biodiesel transport. A sensitivity analysis of alternative multi-functionality procedures for dealing with co-products was performed. The lowest environmental impacts were calculated for mass allocation and the highest for price or energy allocation. Biodiesel produced in Portugal with imported soybean grain had the lowest impacts for all categories and soybean cultivation locations for mass allocation. For price or energy allocation, the pathway with the lowest environmental impacts was determined by the cultivation location. Land-use change had a high influence on the greenhouse gas intensity of biodiesel, while soybean cultivation and transport contributed most to the remaining impact categories. Soybean methyl ester (SME) used in Portugal has the lowest impacts when produced with oil or grain imported from Brazil, instead of importing directly SME. The environmental impacts of biodiesel can be reduced by avoiding land-use change, improving soybean yield and optimizing soybean transportation routes in Brazil.

1. Introduction

The European Union (EU) is highly dependent on imports of oilseeds and related products (protein meals and vegetable oils) to meet demand for food, feed and industrial uses, including biofuel production (Krautgartner et al., 2013). Brazilian soybeans dominate European imports and the vast majority of soybean oil is used in Spain, France, Italy and Portugal (Flach et al., 2012). Fig. 1 shows the relative importance of soybean oil as biodiesel feedstock in EU, Portugal and Brazil. It can be seen that soybean oil is the major feedstock in Portugal and Brazil and the second in EU.

Life-cycle assessment (LCA) has been applied to assess the environmental impacts of soybean based-biodiesel (soybean methyl ester – SME). LCA results vary quite widely, not only due to differences in data and scenarios, but also due to different normative choices in the modeling procedures. For example, regarding greenhouse gas (GHG) emissions, a wide range of results was reported: 0.1–17.8 kg CO_2eq kg^{-1} soybean (Castanheira and Freire, 2013); 10.4–13.3 t CO_2eq ha^{-1} (Ponsioen and Blonk, 2012); 0.4–2.5 kg CO_2eq kg^{-1} soybean oil (Kim and Dale, 2009); 139–1213 g CO_2eq per mile driven (Searchinger and Heimlich, 2008). Some studies accounted for the carbon stock changes due to land-use change (LUC), as well as nitrogen and phosphorus field emissions from soybean cultivation, showing that are highly site-specific (Cavalett and Ortega, 2009, 2010; Reijnders and Huijbregts, 2011; Snyder et al., 2009) and the calculation is complex (Miller, 2010; Del Grosso et al., 2009; Smeets et al., 2009; Smaling et al., 2008; Miller et al., 2006). However, the wide variety of soybean cultivation conditions (Milazzo et al., 2013; Castanheira et al., 2014), as well as the influence of different climate vegetation and soil regions on the results have not been comprehensively addressed in previous research.

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Multifunctional processes are a problem for LCA because usually not all the functional flows are part of the same product system. The question is then, how to allocate the environmental impacts of multifunctional processes to the different product systems (Wardenaar et al., 2012). Different approaches were adopted in the literature to deal with the co-products of soybean biodiesel chain: allocation based on mass (Mourad and Walter, 2011; Miller et al., 2007; Hu et al., 2008), energy (van Dam et al., 2009; Fehrenbach et al., 2007) and market value (Panichelli et al., 2009), as well as system boundary expansion (Huo et al., 2009; Dalgaard et al., 2008; Reinhard and Zah, 2009). Therefore, a sensitivity analysis to alternative allocation procedures should be performed to evaluate the influence on the results, as suggested by ISO standards (ISO, 2006a, b).

Most LCA studies of SME addressed only climate change and only a few other environmental impacts (e.g. eutrophication, acidification). The toxicity impacts originated from pesticides and fertilizers application have not been typically addressed for many reasons, including lack of data and models. Also, according to Rosenbaum et al. (2008), different methods often failed to arrive at the same toxicity characterization score for a substance. No LCA has assessed different pathways for SME consumed in the EU, namely comparing importing biodiesel with importing soybean oil or grain to produce SME in the EU.

The aim of this article is to present an LCA of SME consumed in Portugal comparing three alternative pathways (importing biodiesel, soybean grain or oil). A comprehensive evaluation of four different soybean cultivation locations in Brazil was performed. The impacts were assessed for six categories using the ReCiPe life-cycle impact assessment (LCIA) method (Goedkoop et al., 2012). Toxicity impacts were also assessed with the USEtox method (Rosenbaum et al., 2008), to determine the extent to which the results are influenced by the method applied. This article is organized in four sections, including this introduction. Section 2 describes the life-cycle model and inventory for the three pathways as well as the allocation procedures. Section 3 presents and discusses the results. Section 4 draws the conclusions together.

2. Life-cycle model and inventory

2.1. System boundaries and multifunctionality

A life-cycle (LC) model of SME was implemented for three alternative pathways:

A) biodiesel totally produced in Brazil and exported to Portugal (BR-BR-BR);
B) biodiesel production (transesterification) in Portugal using soybean oil imported from Brazil (BR-BR-PT);
C) biodiesel production and oil extraction in Portugal using soybean imported from Brazil (BR-PT-PT).

Fig. 2 describes the three alternative pathways, including direct LUC, soybean cultivation, oil extraction and refining, biodiesel production (methyl transesterification) and final distribution to the fuel blending facility. Soybean was cultivated in Mato Grosso (MT), Goiás (GO), Paraná (PR) and Rio Grande do Sul (RS), where more than 70% of the total Brazilian soybean was produced between 2009 and 2011 (IBGE, 2012). Indirect LUC carbon emissions were not addressed, given the lack of available data on the indirect conversion of soils and since there is no consensus on how to account for this (European Commission, 2010a). The functional unit chosen was 1 MJ of SME, measured in terms of the Lower Heating Value, LHV (LHV of SME = 37 MJ kg^{-1}).

The SME system is multifunctional, with soybean oil and soybean meal being produced in the oil extraction, as well as glycerin and SME in the transesterification (Fig. 2). These co-products have different functions and thus, no single allocation approach is deemed appropriate. According to Guinée et al. (2004), there is not a 'correct' way to address the multifunctionality problem since "the multi-functionality problem is an artefact of wishing to isolate one function out of many. As artefacts can only be cured in an artificial way, there is no 'correct' way of solving the multi-functionality problem, even not in theory." In addition, according to ISO 14044 (2006b) "whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach" (ISO, 2006b). A sensitivity analysis to allocation approaches in LCAs of biofuels adopting energy as functional unit can be found in many published studies (e.g. Huo et al., 2009; Reinhard and Zah, 2009; Malça and Freire, 2006, 2011, 2014). In this context, three allocation procedures were adopted in this article based on mass, energy and price of products.

Table 1 presents the physical properties and prices of products, as well as the allocation factors. Energy allocation factors were calculated based on the LHV of products. The LHV was calculated based on the dry matter, the latent heat of vaporization of water at 25 °C and the wet basis moisture content of products (Fehrenbach et al., 2007). The wet content of soybean meal and glycerin (13% and 9%) were average values calculated based on the specific data of Portuguese industrial processes. The wet content of the remaining co-products were considered to be zero (Fehrenbach et al., 2007).

Price allocation factors were obtained based on the world average annual prices (US$) of oil and meal (2009–2013 period). The average annual price of biodiesel (2009–2013 period) was based on the price paid to biodiesel producers, according with the Portuguese regulation. The price of glycerin was based on market information provided by Portuguese biodiesel companies. To

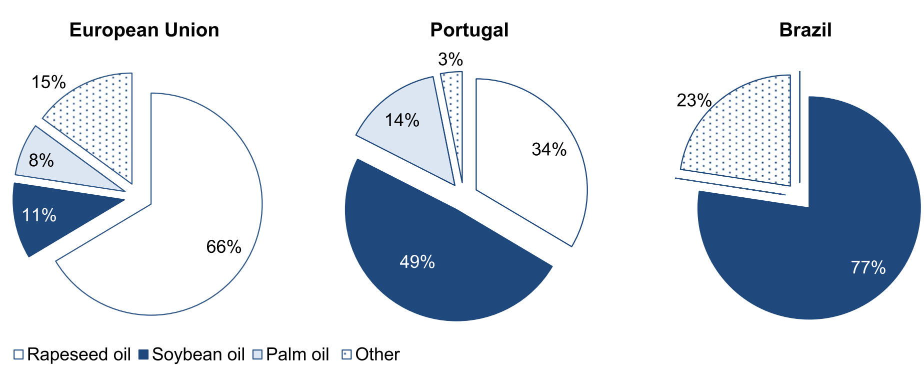

Fig. 1. Feedstock used for biodiesel production in the European Union, Portugal and Brazil.
Source: ANP, 2013; DGEG, 2012; Flach et al., 2012.